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Electronic Apparatus, Silicon-on-Insulator Integrated
Circuits, and Fabrication Methods

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**Electronic Apparatuses, Silicon-on-Insulator Integrated Circuits, and
Fabrication Methods**

RELATED PATENT DATA

[0001] This patent is related to U. S. Patent Application Serial No. 10/443,335, filed on May 21, 2003, entitled "Silicon Oxycarbide Substrates for Bonded Silicon on Insulator," listing Leonard Forbes as the inventor, the entirety of which is herein incorporated by reference.

TECHNICAL FIELD

[0002] The invention pertains to electronic apparatuses, silicon-on-insulator integrated circuits, and fabrication methods for the same. The invention also pertains to memory devices including such electronic apparatuses and integrated circuits. The invention further pertains to computer systems including such memory devices.

BACKGROUND OF THE INVENTION

[0003] Almost half of the energy expended by some semiconductor-based electronic apparatuses, such as silicon microchips, during their manufacture and lifetime is spent just to produce the semiconductor material, such as silicon wafer material. Another quarter is spent during the operating lifetime of the electronic apparatuses. Any technique that reduces the energy associated with fabrication of the semiconductor material, such as a silicon wafer, and power consumption during

operation may reduce the overall cost of the apparatus, such as a silicon microchip integrated circuit. Silicon-on-insulator technology can result in lower power consumption and also increase the speed of operation of integrated circuits due to a reduction in stray capacitance.

[0004] A variety of techniques may be used to implement silicon-on-insulator (SOI) technology including, but not limited to, SIMOX (Separation by IMplantation of OXYgen), SPIMOX (Separation by Plasma IMplantation of OXYgen), SOS (Silicon-On-Sapphire), bonding silicon wafers on oxidized silicon wafers, and forming thin film polysilicon on a glass substrate, such as for thin film transistor (TFT) technology used in liquid crystal displays. Even so, the TFT technology in display applications is often of lower performance since the silicon material is not monocrystalline and has grain boundaries.

[0005] Although the bonded wafer technology may be preferred in certain circumstances, one problem with such technology is the difference in the coefficient of thermal expansion (CTE) between the bonded materials. For example, in the case of a silicon wafer having a CTE of 2.6×10^{-6} centimeters/(centimeters K) (cm/(cm K)) bonded to an oxidized silicon wafer having a CTE of 0.5×10^{-6} cm/(cm K) there is a sufficient mismatch of the CTE to produce excessive stress and exceed the strain limit of the materials. If the strain is too large, then the materials will plastically deform by the introduction of dislocations, fracture and yield, or excessive wafer bowing and/or warping. Some attempts have been made to bond silicon to compliant substrates using low viscosity borophosphosilicate glass films

that flow to reduce the stress. However, such attempts have not produced satisfactory results.

[0006] Accordingly, a desire exists to bond semiconductive materials to an insulative substrate without introducing excessive stress.

SUMMARY OF THE INVENTION

[0007] In one aspect of the invention, an electronic apparatus includes an insulative substrate containing an aluminum-based glass and a layer containing a semiconductive material over the substrate. By way of example, the insulative substrate can include aluminum oxycarbide. The substrate can further include aluminum carbide, silicon carbide, and α -alumina. The insulative substrate can exhibit a CTE sufficiently close to a CTE of the semiconductive material such that a strain of less than 1% would exist between a 1000 Angstrom thickness of the semiconductive material layer and the insulative substrate. The semiconductive material layer may have a thickness of about 1000 Angstroms or less. Also, the strain may be less than 0.6%. The semiconductive material layer can include monocrystalline silicon.

[0008] In another aspect of the invention, a silicon-on-insulator integrated circuit includes an insulative glass substrate containing aluminum oxycarbide, a monocrystalline silicon layer on and in contact with the substrate, and a semiconductor device that includes at least a part of the silicon layer.

[0009] In a further aspect of the invention, an electronic apparatus fabrication method includes forming an insulative substrate containing an aluminum-based

glass and forming a layer containing a semiconductive material over the substrate. By way of example, forming the insulative substrate can include forming a mixture of a powder containing aluminum, a powder containing silicon, and a powder containing carbon, mechanically activating the mixture and allowing the mixture to react by spontaneous ignition, and forming the reacted mixture into a plate. Also, forming the semiconductive material layer can include removing a layer of silicon from a monocrystalline silicon wafer and bonding the silicon layer to the insulative substrate.

[0010] Also, included among aspects of the invention are memory devices having a plurality of memory cells that include at least a part of the semiconductive material layer over the insulative substrate that contains an aluminum-based glass. Such memory devices may be part of a computer system that also includes a microprocessor. The memory devices may be dynamic random access memory.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

[0012] Fig. 1 shows a partial, sectional view of a semiconductive material at a process step according to one aspect of the invention.

[0013] Fig. 2 shows a partial, sectional view of the semiconductive material of Fig. 1 at a subsequent process step bonded to a substrate.

[0014] Fig. 3 shows a partial, sectional view of the Fig. 2 substrate at a subsequent process step.

[0015] Fig. 4 shows an enlarged, partial, sectional view of the Fig. 3 substrate at a subsequent process step.

[0016] Fig. 5 is a chart demonstrating plastic deformation and elastic strain for a range of silicon layer thickness.

[0017] Fig. 6 shows a diagrammatic view of computer illustrating an exemplary application of the present invention.

[0018] Fig. 7 is a block diagram showing particular features of the motherboard of the Fig. 6 computer.

[0019] Fig. 8 shows a high level block diagram of an electronic system according to an exemplary aspect of the present invention.

[0020] Fig. 9 shows a simplified block diagram of an exemplary device according to an aspect of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Aluminum-based glass is herein identified as a suitable substrate for SOI substrates. In keeping with the aspects of the invention described herein, aluminum-based glass can exhibit CTE sufficiently close to the CTE of monocrystalline silicon such that any mismatch of the CTE will not result in excessive stress nor exceed the strain limit of the materials. Fig. 5 is a chart showing yield limits for elastic strain of various silicon layer thicknesses. The hatched region of Fig. 5 represents stresses for a given thickness that were sufficient to exceed the strain limit of the silicon layer, resulting in plastic deformation and/or defects in the silicon layer.

[0022] The three data points on the curve that represents the yield limit are experimental values for 100 Angstrom, 500 Angstrom, and 3000 Angstrom thicknesses. As may be appreciated from Fig. 5, for a silicon layer having a thickness of 1000 Angstroms or less, a strain of 1% or less will not exceed the yield limit for the silicon layer. However, preferably any mismatch of CTE between a silicon layer and an aluminum-based glass substrate will be limited such that strain does not exceed 0.6%. For the aluminum-based glass compositions described herein, a strain of from about 0.2% to about 0.6% is expected.

[0023] According to one aspect of the invention, an electronic apparatus may be fabricated from a method that includes forming an insulative substrate containing an aluminum-based glass and forming a layer containing a semiconductive material over the substrate. By way of example, the method can further include forming a semiconductor device that includes at least a part of the semiconductive material layer. Also, the semiconductive material layer may be formed on and in contact with the insulative substrate. The insulative substrate may exhibit a CTE sufficiently close to a CTE of the semiconductive material layer such that a strain of less than 1% would exist between a 1000 Angstrom thickness of the semiconductive material layer and the insulative substrate. The semiconductive material layer may have a thickness of about 1000 Angstroms or less, but preferably about 1000 Angstroms. Also, the strain can be less than 0.6%.

[0024] The insulative substrate that contains an aluminum-based glass may be formed using any method known to those skilled in the art that is sufficient to produce a material compliant with the other aspects of the invention described

herein. One particularly suitable method involves forming mixture of a powder containing aluminum, a powder containing silicon, and a powder containing carbon. The mixture may be mechanically activated and allowed to react by spontaneous ignition. The reacted mixture may then be formed into an aluminum-based glass plate using conventional firing techniques. The glass plate may be polished and cut into silicon wafer size shapes to act in the place of a conventional monocrystalline silicon wafer. Further chemical-mechanical polishing on the glass wafers is possible, if desired.

[0025] Exposing the mixture to air constitutes one manner in which the mixture may be allowed to react. Alternatively, allowing the mixture to react can include exposing the mixture to oxygen gas and to an inert gas excluding nitrogen. The final products within the reacted mixture exposed to air include, but are not limited to, aluminum oxycarbide, aluminum nitride, aluminum carbide, silicon carbide, and α -alumina. If the method involves exposing the mixture to oxygen gas and to an inert gas excluding nitrogen, then aluminum nitride is generally not found among the final products of the reacted mixture. Argon constitutes one example of a suitable inert gas that excludes nitrogen. The inert gas is provided along with the oxygen gas as a diluent adjusting oxygen concentration to avoid an explosive reaction.

[0026] As an example, a self-propagating high-temperature synthesis (SHS) of aluminum oxycarbide is described by Tsuchida et al., "Self-Combustion Reaction Induced by Mechanical Activation of Al-Si-C Powder Mixtures," European Journal of Solid State and Inorganic Chemistry, Vol. 32, No. 7-8, pg. 629-638, 1995. A similar

SHS for aluminoborate glass may be modified in accordance with the aspects of the invention described herein to produce aluminum oxycarbide. One example of aluminoborate glass SHS is described by Yi et al., "Combustion Synthesis of Aluminoborate Glass Matrices," Journal of Materials Synthesis and Processing, Vol. 8, No. 1, pg. 15-20, 2000.

[0027] The composition of the mixture of a powder containing aluminum, a powder containing silicon, and a powder containing carbon can be adjusted to obtain a particular CTE in a plate formed from the reacted mixture to better match the CTE of the semiconductive material layer. Unfortunately, the CTE of aluminum oxycarbide is not yet well defined and is expected to be somewhat higher than the CTE of monocrystalline silicon. Regardless, the CTE of the other constituents of aluminum-based glass described herein are sufficiently close to the CTE of monocrystalline silicon such that monocrystalline silicon having a thickness of about 1000 Angstroms or less remains a suitable semiconductive material layer. A glass plate derived from SHS of Al-Si-C powder mixtures in air or argon-diluted oxygen is expected to produce a strain of about 0.2% to about 0.6% which, as shown in Fig. 5, does not exceed the yield limit of a silicon layer with a thickness of 1000 Angstroms or less. Notably, silicon carbide has a CTE of from 3.9 to 4.0×10^{-6} cm/(cm K), aluminum oxide (alumina) has a CTE of from 7 to 8×10^{-6} cm/(cm K), and aluminum nitride has a CTE of 4.6×10^{-6} cm/(cm K). These may be compared to the silicon CTE of 2.6×10^{-6} (cm/(cm K). The CTE for aluminum carbide is not available.

[0028] In the electronic apparatus fabrication method, forming the semiconductive material layer can include removing a layer of silicon from a monocrystalline silicon wafer and bonding the silicon layer to the insulative substrate. Figs. 1-3 illustrate one example of a method of forming the semiconductive material layer. In Fig. 1, ions 14 are implanted into a semiconductive material 10 forming an implanted region 12. Monocrystalline silicon, such as found in a bulk silicon wafer, constitute one material suitable for use as semiconductive material 10. In Fig. 2, semiconductive material 10 is inverted and placed in contact with substrate 16. Substrate 16 may constitute an insulative substrate containing an aluminum-based glass. In Fig. 2, implanted region 12 of semiconductive material 10 is shown on and in contact with substrate 16. As one alternative, semiconductive material 10 shown in Fig. 1 may include an oxide layer over implanted region 12 such that the oxide layer forms an interface layer between implanted region 12 and substrate 16 of Fig. 2.

[0029] In Fig. 2, implanted region 12 is bonded to substrate 16. Subsequently, the majority of semiconductive material 10 is removed by virtue of a fracture occurring along the boundary of implanted region 12 to produce the structure shown in Fig. 3. The semiconductive material of implanted region 12 bonded to substrate 16 in Fig. 3 thus forms a SOI substrate that may be used for subsequent device fabrication. The method may further include chemically-mechanically polishing implanted region 12 bonded to substrate 16 in Fig. 3. The remaining semiconductive material 10 not bonded to substrate 16 may be subsequently chemically-mechanically polished and used again by implanting ions

14 to form another implanted region 12 that may be bonded to another substrate 16. Such process may be repeated and semiconductive material 10 gradually consumed in the process until an insufficient amount remains.

[0030] In the case where an oxide layer is formed over implanted region 12 shown in Fig. 1 to form an interface layer in the bonded structure of Fig. 2, such oxide layer may constitute a buried oxide in the structure of Fig. 3. In the event that substrate 16 is not an insulative substrate, such buried oxide isolates the semiconductive material of implanted region 12 from the non-insulative material of substrate 16. However, according to aspects of the invention herein, substrate 16 may be an insulative substrate and such buried oxide is not necessarily needed for isolation purposes. Buried oxide may nevertheless be desired for other purposes.

[0031] The implanting of ions to form implanted region 12 may include implanting hydrogen ions (H^+) and/or other ions that may be suitable according to the knowledge of those skilled in the art. The hydrogen ions may include deuterium ions. The bonding of implanted region 12 to substrate 16 may be accomplished by heating to at least 400° C. A temperature range of from about 400 to about 600 °C provides suitable bonding of a monocrystalline silicon layer to an aluminum-based glass substrate and the bond thus formed may be strengthened by subsequently raising the temperature to from about 800 to about 1000 °C. Although minima and maxima are listed for the above described temperature ranges, it should be understood that more narrow included ranges may also be desirable. Such more narrow ranges may be particularly suitable for bonding certain material combinations.

[0032] The Smart-Cut ® process used by Soitec of Benin, France is one example of a method that involves implanting ions into a wafer and bonding a silicon layer to a substrate by thermal treatment. Use and application of the Smart-Cut ® process as well as other suitable bonding processes are described in U. S. Patent No. 6,093,623, entitled "Methods for Making Silicon-On-Insulator Structures," issued to Leonard Forbes, and incorporated herein by reference for its pertinent and supported teachings. The Smart-Cut ® process is also described in A. J. Auberton-Herve, "SOI: Materials to Systems," Digest of the International Electron Device Meeting, San Francisco, pg. 3-10, Dec. 1996. Even though the Smart-Cut ® process is conventionally used to bond an oxidized silicon interface layer to a silicon wafer, such method may be modified to be of use in accomplishing the aspects of the inventions described herein.

[0033] Bonding of implanted region 12 or an oxide layer formed on implanted region 12 may also be accomplished by plasma enhanced bonding such as described in Suni et al., "Effects of Plasma Activation on Hydrophilic Bonding of Si and SiO₂," J. Electrochem Soc., Vol. 149, No. 6, pg. G348-51, June 2002. That is, low-pressure argon or oxygen plasma may be used to activate a surface of implanted region 12 or an oxide layer over implanted region 12 to be bonded to substrate 16. Such activation promotes hydrophilic bonding and may be followed by annealing at about 400 to about 600 °C. The bond may be strengthened by raising the temperature to from about 800 to about 1000 °C.

[0034] Laser assisted annealing may used instead of or in addition to plasma enhanced bonding and/or thermal annealing to bond a layer of semiconductive

material to an aluminum-based glass. Methods for bonding glass to silicon with lasers known to those of skill in the art may be adapted to the aspects of the invention described herein. For example, a beam from a compact Nd:YAG laser in the power range of 50 to 100 Watts may be applied to the structure shown in Fig. 2 and absorbed at the interface between implanted region 12 and substrate 16, bonding the two materials. Laser assisted annealing may be a suitable alternative to anodic bonding of oxide to glass or silicon to glass that is not appropriate for a CMOS because of a high alkali ion content of the glass.

[0035] The SOI substrates fabricated according to the aspects of the inventions described herein can be processed in a manner similar to silicon-on-sapphire wafers and semiconductor devices formed to comprise at least a part of the semiconductive material layer. In the case of ultra-thin CMOS device technology, fully depleted devices can be fabricated by masking selected device areas with oxide and nitride followed by oxidizing the unmasked silicon between the masked device mesas. Remaining device structures can be formed using conventional techniques. In the case of partially depleted CMOS device technology, with or without floating bodies, the semiconductive material layer may be patterned by a trench isolation process, such as a SIMOX process. Remaining device structures can be formed using conventional techniques. In either case, an isolated semiconductor device area is produced on an insulating substrate. Stray capacitances can be minimized because the device drain, source, and/or collectors are on an insulating glass layer. Interconnection wire may be formed over the isolation oxide and insulating substrate thereby minimizing wiring capacitance.

Reducing such parasitic capacitances reduces power consumption during integrated circuit operation and increases speed of operation.

[0036] Accordingly, the use of aluminum oxycarbide glass substrates serves to reduce the energy consumption and costs compared to using high quality monocrystalline substrates where the majority of the monocrystalline substrate is not used in any semiconductor device function and serves only as a carrier substrate. Thus, the aspects of the invention avoid a waste of resources that can occur with use of high quality and high cost monocrystalline silicon substrates. Fortunately, the aspects of the invention overcome the problem of mismatch in CTE that was previously apparent in attempting to produce semiconductor-based integrated circuits on low cost glass substrates.

[0037] According to another aspect of the invention, a SOI integrated circuit fabrication method includes forming a mixture of a powder containing aluminum, a powder containing silicon, and a powder containing carbon and mechanically activating the mixture, allowing the mixture to react by spontaneous ignition. The reacted mixture is formed into a glass substrate comprising aluminum oxycarbide. The method further includes removing a layer of silicon from a monocrystalline silicon wafer, bonding the silicon wafer on and in contact with the glass substrate, and forming a semiconductor device that includes at least a part of the silicon layer.

[0038] Fig. 4 shows an enlarged view of a portion of the structure of Fig. 3 and additionally shows exemplary semiconductor devices that include at least a part of a semiconductive material layer. The exemplary devices are isolated by a trench isolation region 32. In the right-half of Fig. 4, a capacitor dielectric 18 is formed

within a container capacitor opening in the semiconductive material. An electrode is formed over capacitor dielectric 18. A variety of alternative capacitor structures are conceivable that also include at least a part of the semiconductive material layer. In the capacitor shown, the semiconductive material layer functions as an electrode.

[0039] In the left-half of Fig. 4, a field effect transistor is shown having a gate line 22 formed over a gate dielectric 26 on the semiconductive material layer and a cap 24 formed over the gate line. Spacers 28 are formed on the sidewalls of gate line 22 and over source/drain diffusion regions 30 in the semiconductive material. Accordingly, the transistor of Fig. 4 constitutes a device that includes at least a part of the semiconductive material layer. A variety of other transistor structures as well as other device structures are conceivable.

[0040] According a further aspect of the invention, an electronic apparatus includes an insulative substrate containing an aluminum-based glass and a layer containing a semiconductive material over the substrate. By way of example, a semiconductive device may be provided that includes at least a part of the semiconductive material layer. The semiconductive material layer can be on and in contact with the insulative substrate. The semiconductive material layer may have a thickness of about 1000 Angstroms or less. Also, the semiconductive material layer can include monocrystalline silicon. Further, the semiconductive material layer may consist of monocrystalline silicon. The insulative substrate may contain aluminum oxycarbide. Also, the insulative substrate can exhibit a CTE sufficiently close to a CTE of the semiconductive material layer such that a strain of less than

1% would exist between a 1000 Angstrom thickness of the semiconductive material layer and the insulative substrate. Preferably, the strain would be less than 0.6%.

[0041] The described property of the insulative substrate exhibiting a CTE sufficiently close to a CTE of the semiconductive material layer can be obtained even though little or no data exists regarding the CTE of certain components of the aluminum-based glass. For example, the aluminum-based glass can include aluminum carbide, silicon carbide, and α -alumina in addition to aluminum oxycarbide. The CTE for aluminum oxycarbide and aluminum carbide is not well defined. Nevertheless, the composition of the aluminum-based glass can be systematically varied in a designed experiment in keeping with the aspects of the invention. The insulative substrate can be formed, a layer containing a semiconductive material formed over the substrate, and any resulting strain subsequently measured using methods known to those skilled in the art. Using well-known principles for statistical design of experiments, the influence of composition on strain can be determined. In particular, the influence of aluminum oxycarbide and/or aluminum carbide composition on strain can be established. Thus, the absence of well-defined CTE data for some components of the aluminum-based glass does not prevent obtaining an electronic apparatus that avoids the region of excessive stress shown in Fig. 5.

[0042] According to a still further aspect of the invention, a silicon-on-insulator integrated circuit includes an insulative glass substrate containing aluminum oxycarbide, a monocrystalline silicon layer on and in contact with the substrate, and a semiconductor device that includes at least a part of the silicon

layer. The benefits and advantages of such an integrated circuit are described above.

[0043] Fig. 6 illustrates generally, by way of example, but not by way of limitation, an embodiment of a computer system 400 according to an aspect of the present invention. Computer system 400 includes a monitor 401 or other communication output device, a keyboard 402 or other communication input device, and a motherboard 404. Motherboard 404 can carry a microprocessor 406 or other data processing unit, and at least one memory device 408. Memory device 408 can comprise various aspects of the invention described above. Memory device 408 can comprise an array of memory cells, and such array can be coupled with addressing circuitry for accessing individual memory cells in the array. Further, the memory cell array can be coupled to a read circuit for reading data from the memory cells. The addressing and read circuitry can be utilized for conveying information between memory device 408 and processor 406. Such is illustrated in the block diagram of the motherboard 404 shown in Fig. 7. In such block diagram, the addressing circuitry is illustrated as 410 and the read circuitry is illustrated as 412.

[0044] In particular aspects of the invention, memory device 408 can correspond to a memory module. For example, single in-line memory modules (SIMMs) and dual in-line memory modules (DIMMs) may be used in the implementation that utilizes the teachings of the present invention. The memory device can be incorporated into any of a variety of designs that provide different methods of reading from and writing to memory cells of the device. One such

method is the page mode operation. Page mode operations in a DRAM are defined by the method of accessing a row of a memory cell arrays and randomly accessing different columns of the array. Data stored at the row and column intersection can be read and output while that column is accessed.

[0045] An alternate type of device is the extended data output (EDO) memory that allows data stored at a memory array address to be available as output after the addressed column has been closed. This memory can increase some communication speeds by allowing shorter access signals without reducing the time in which memory output data is available on a memory bus. Other alternative types of devices include SDRAM, DDR SDRAM, SLDRAM, VRAM and Direct RDRAM, as well as others such as SRAM or Flash memories.

[0046] Fig. 8 illustrates a simplified block diagram of a high-level organization of various embodiments of an exemplary electronic system 700 of the present invention. System 700 can correspond to, for example, a computer system, a process control system, or any other system that employs a processor and associated memory. Electronic system 700 has functional elements, including a processor or arithmetic/logic unit (ALU) 702, a control unit 704, a memory device unit 706 and an input/output (I/O) device 708. Generally, electronic system 700 will have a native set of instructions that specify operations to be performed on data by the processor 702 and other interactions between the processor 702, the memory device unit 706 and the I/O devices 708. The control unit 704 coordinates all operations of the processor 702, the memory device 706 and the I/O devices 708 by continuously cycling through a set of operations that cause instructions to be

fetched from the memory device 706 and executed. In various embodiments, the memory device 706 includes, but is not limited to, random access memory (RAM) devices, read-only memory (ROM) devices, and peripheral devices such as a floppy disk drive and a compact disk CD-ROM drive. One of ordinary skill in the art will understand, upon reading and comprehending this disclosure, that any of the illustrated electrical components are capable of being fabricated to include DRAM cells in accordance with various aspects of the present invention.

[0047] Fig. 9 is a simplified block diagram of a high-level organization of various embodiments of an exemplary electronic system 800. The system 800 includes a memory device 802 that has an array of memory cells 804, address decoder 806, row access circuitry 808, column access circuitry 810, read/write control circuitry 812 for controlling operations, and input/output circuitry 814. The memory device 802 further includes power circuitry 816, and sensors 820, such as current sensors for determining whether a memory cell is in a low-threshold conducting state or in a high-threshold non-conducting state. The illustrated power circuitry 816 includes power supply circuitry 880, circuitry 882 for providing a reference voltage, circuitry 884 for providing the first wordline with pulses, circuitry 886 for providing the second wordline with pulses, and circuitry 888 for providing the bitline with pulses. The system 800 also includes a processor 822, or memory controller for memory accessing.

[0048] The memory device 802 receives control signals 824 from the processor 822 over wiring or metallization lines. The memory device 802 is used to store data that is accessed via I/O lines. It will be appreciated by those skilled in the art that

additional circuitry and control signals can be provided, and that the memory device 802 has been simplified to help focus on the invention. At least one of the processor 822 or memory device 802 can include a capacitor construction in a memory device of the type described previously herein.

[0049] The various illustrated systems of this disclosure are intended to provide a general understanding of various applications for the circuitry and structures of the present invention, and are not intended to serve as a complete description of all the elements and features of an electronic system using memory cells in accordance with aspects of the present invention. One of the ordinary skill in the art will understand that the various electronic systems can be fabricated in single-package processing units, or even on a single semiconductor chip, in order to reduce the communication time between the processor and the memory device(s).

[0050] Applications for memory cells can include electronic systems for use in memory modules, device drivers, power modules, communication modems, processor modules, and application-specific modules, and may include multilayer, multichip modules. Such circuitry can further be a subcomponent of a variety of electronic systems, such as a clock, a television, a cell phone, a personal computer, an automobile, an industrial control system, an aircraft, and others.

[0051] In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its

forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.